RESEARCH DEPARTMENT

A COMPARISON OF TWO ZOOM LENSES

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W.N. Sproson, M.A.
M. Gilbert, Ph.D., B.Sc., D.I.C.

W Proctor Wilson

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1. INTRODUCTION.

The two zoom lenses in question were manufactured by W. Watson Ltd., Barnet, and by Taylor, Taylor and Hobson Ltd., Leicester. The investigation described was undertaken in view of the interest shown in these lenses by Television Outside Broadcasts Department and other specialist departments in Engineering Division.

A brief specification of the Watson zoom lens is as follows:

Focal length range	3 – 15 in.	or	6 – 30 in.
Maximum aperture throughout the full range	f/4·5		f/9
Minimum focusing distance	10 ft. 6 in.		10 ft. 6 in.

The corresponding specification for the Taylor, Taylor and Hobson zoom lens is as follows:

Focal length range	5 – 25 in.	or	8 – 40 in.
Maximum aperture throughout the full range	f/5·6		f/8
Minimum focusing distance	25 ft.		25 ft.

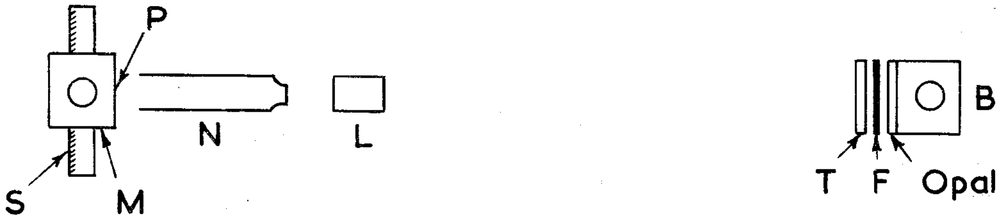
In both cases the change of focal-length range is achieved by changing the back component of the lens. Both interchangeable rear components were available with the Watson lens; in the case of the Taylor, Taylor and Hobson lens only the 5 – 25 in. range was available. It should be noted that the change of rear component alters the back focal distance and hence in operational practice new adjustments and a different mounting of the lens are necessary.

The tests can be divided into two main groups, (a) determination of axial modulation/frequency characteristics and (b) general appraisal of image quality over the 40 mm diagonal field required for the image orthicon camera. Some further remarks will be added about mechanical features of the two lenses.

2. MEASUREMENT OF THE AXIAL MODULATION/FREQUENCY CHARACTERISTICS.

The general method of measuring the modulation depth of the aerial image produced by a lens has already been described in detail in Research Report No. T.039. The following brief account is repeated only for the sake of completeness.

A range of square wave grating-pattern test objects is used and the aerial image formed by the lens is magnified by a microscope objective. The brightness distribution of the magnified aerial image is measured by a multiplier photoelectric cell, a narrow slit selecting a portion of the magnified aerial image and allowing the light flux from this part of the image to pass through to the photocell. As the narrow slit scans the image, the maximum and minimum intensities are observed and the modulation is calculated by dividing the difference between the two readings by their sum. The minimum reading does not include the photocell dark current; this is balanced out from the instrument reading. Fig. 1 gives a schematic of the method, in which the various elements have been indicated.



B.	Light source	N.	Microscope (less eyepiece)
F.	Neutral and/or colour filter	P.	Narrow slit
T.	Test Pattern	M.	Box housing photomultiplier
L.	Lens under test	S.	Scale of travelling microscope stand

Fig. 1 - Method of measuring the modulation characteristics of lenses.

The results obtained for the two ranges of the Watson lens and the single range of the Taylor, Taylor and Hobson lens are given in Tables 1-4. Tables 1 and 2 give the directly-measured modulation to square waves at pattern frequencies corresponding to the video frequencies of 0, 1, 2 and 3 Mc/s for the B.B.C. 405-line, 50-field, television system using the image orthicon camera. In this instance 3 Mc/s is equivalent to 8 patterns per mm. Tables 3 and 4 give the derived results in which the modulation to sine waves is expressed in decibels. A complete set of graphs illustrating Tables 1-4 would be rather cumbersome, and hence a simplified presentation giving the most relevant data is all that is attempted here. Fig. 2 shows the sine wave modulation expressed in decibels at a pattern frequency corresponding to 3 Mc/s for the various ranges of focal length at the maximum aperture. It will be noticed that the shape of curve for the two Watson ranges is similar although the longer focal length range gives somewhat lower values of modulation. On both ranges, the Watson lens begins to lose modulation depth rapidly once the half-way mark is passed (assuming in both cases that a start is made from the short-focal-length end). This effect should not be confused with loss of focus, although on the final television picture it produces a very similar effect. In actual fact, the image per se remains sharp throughout the whole of the zoom range but the blacks in the test pattern become a medium grey. The effect is very obvious if the image of a square wave test pattern is examined by a medium power microscope (x70). At the low-focal-length end of the range the magnified image shows good blacks and whites with sharp edges; at the other end of the range the blacks are clearly no longer black, although the edges are still sharp. In fairness to the manufacturers, it should be pointed out that their

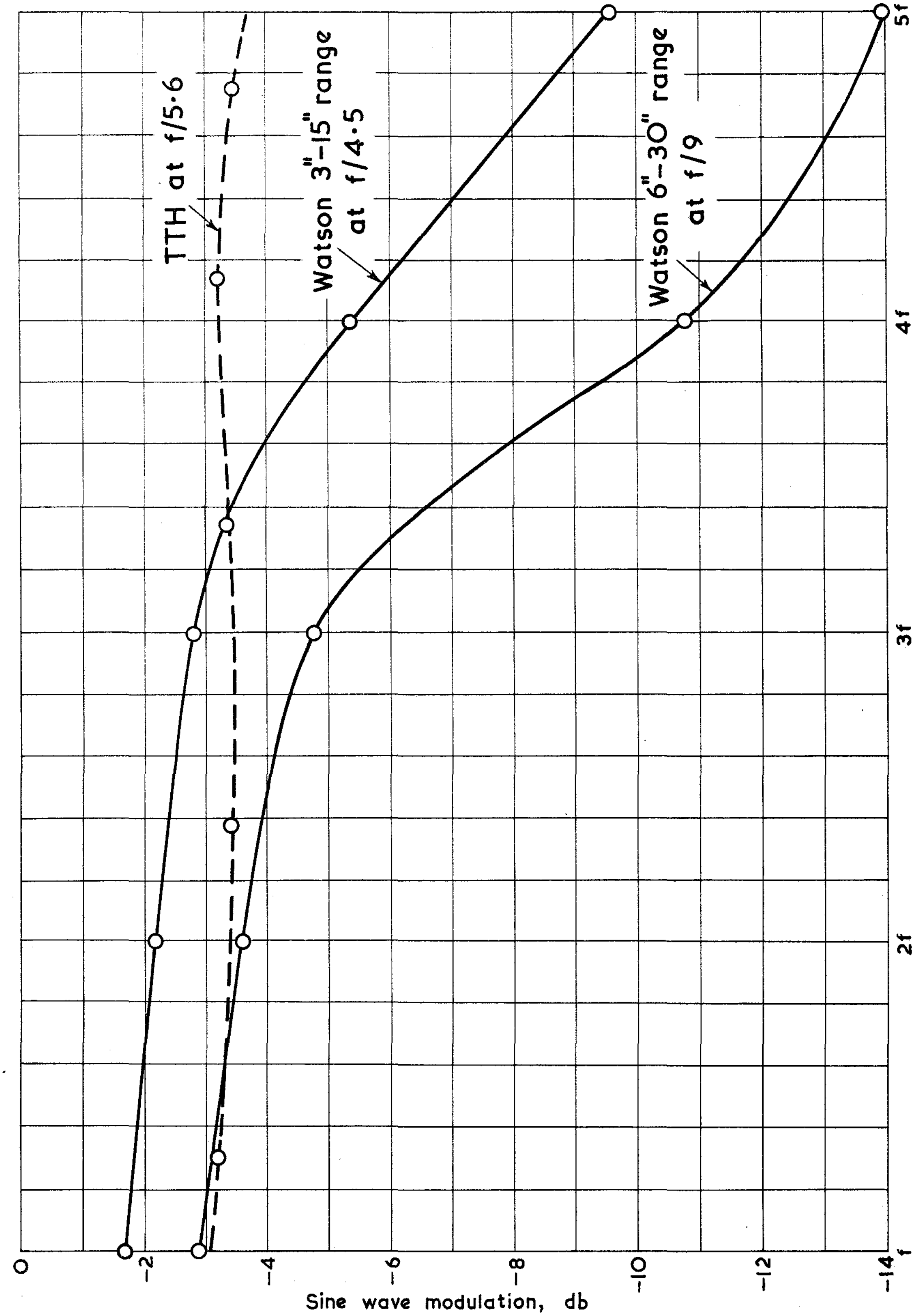


Fig. 2

Modulation (sine wave) at 3 Mc/s for Watson and TTH Zoom lenses at full aperture

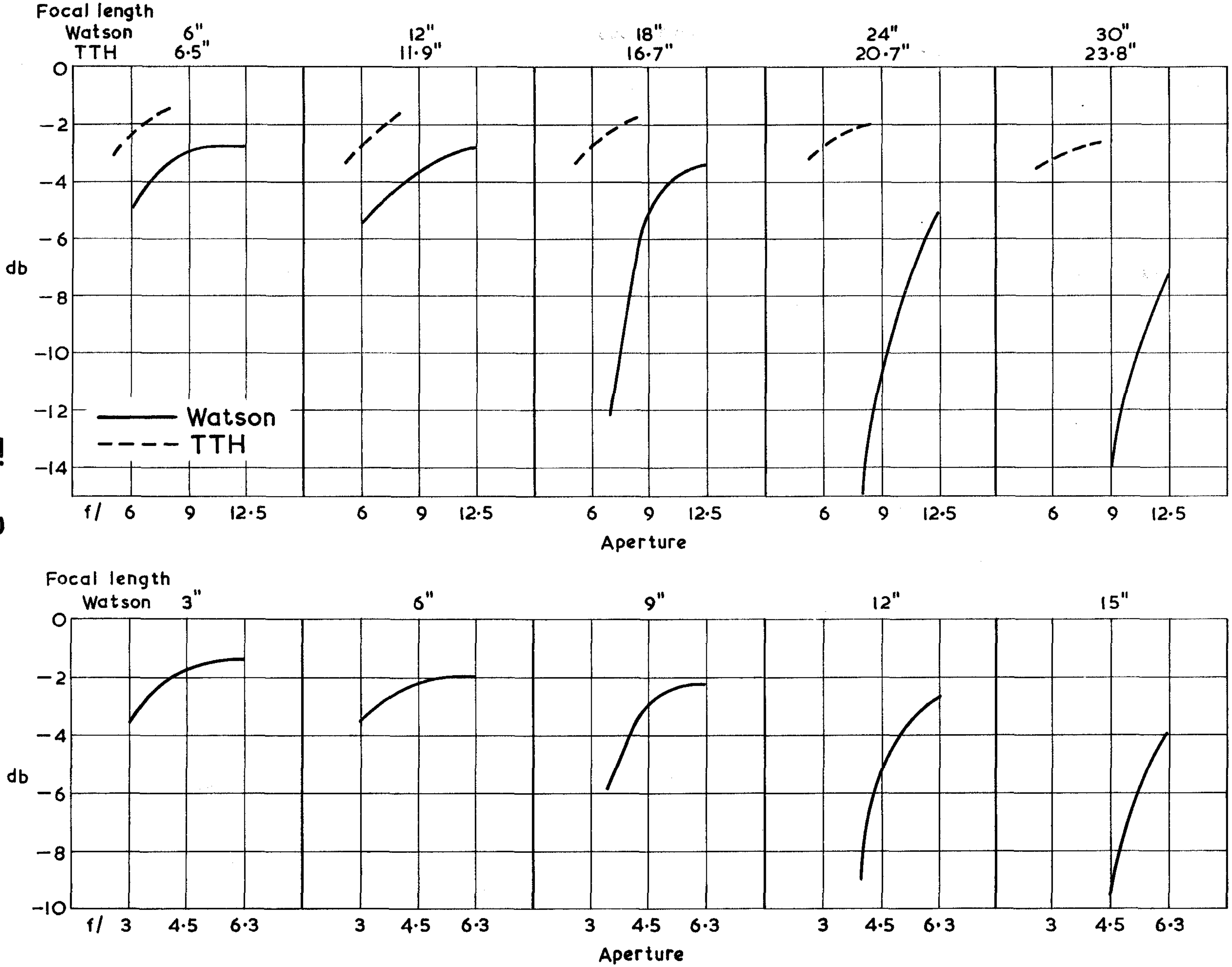


Fig. 3

Watson Zoom No.4 and TTH Varotal lens.

Modulation in db to sine wave at 3 Mc/s for various apertures.

recommended maximum aperture is f/6·3 for the 3 – 15 in. range and f/12·5 for the 6 – 30 in. range. As Tables 1 and 3 show, the Watson lens is appreciably better when used at these apertures and gives a satisfactory performance at f/6·3 in the 3 – 15 in. range: the performance at f/12·5 in the 6 – 30 in. range still leaves something to be desired at the longer focal-length values. The fact remains, however, that at the maximum available aperture, the performance of the Watson lens is as shown in Fig. 2 and cannot be regarded as satisfactory.

In complete distinction to the performance given by the Watson lens, the Taylor, Taylor and Hobson lens gives approximately constant modulation at 3 Mc/s over the whole of its range, maintaining a figure of approximately – 3·3 db. There is a slight drop to – 3·5 db at the longest focal length but the change is so slight that it is probably within the experimental error. A slight loss of modulation with a long-focal-length lens has been observed on previous tests; in the present case we have a modulation of – 3·5 db for a 25-inch f/5·6 lens. This compares very favourably with the best that can be achieved with fixed-focus lenses.

Another form of comparison is plotted in Fig. 3. Sine wave modulation expressed in decibels is plotted against aperture for various values of focal length over the complete range. The Taylor, Taylor and Hobson lens is compared with the 6 – 30 in. range of the Watson lens and the curves show that for a given aperture, the Taylor, Taylor and Hobson lens is superior. The Taylor, Taylor and Hobson lens transmits two and a half times the light flux as well as having a much higher modulation index. It is not possible to make a comparison with the 3 – 15 in. range of the Watson lens as the focal-length ranges are too dissimilar.

It should be pointed out that the values of Tables 1 – 4 for zero frequency* are, of necessity, produced by extrapolation. Usually there is relatively little ambiguity about the d.c. value as the response is fairly flat near zero frequency. In the case of the Watson lenses, the curves are less easy to extrapolate in the neighbourhood of d.c. and some of the figures quoted in Tables 1 and 2 are subject to much greater uncertainty than is usual. The values at 1, 2 and 3 Mc/s are the results of direct measurement or interpolation and are subject only to the usual experimental error, which is of the order of one or two per cent.

Summarising the results of these modulation/frequency measurements, we may say that the Taylor, Taylor and Hobson lens shows a high degree of consistency irrespective of focal-length setting, but that the Watson lens shows a very poor performance at the longer focal lengths in both its ranges, when used at the maximum aperture which is available throughout the full zoom range.

3. PHOTOGRAPHIC AND VISUAL EXAMINATION OF GENERAL IMAGE QUALITY.

The measurements described in Section 2 give precise information about the image-forming properties of these lenses on and near to the optical axis, but give no information as to whether the covering power of the lens is adequate. To test this, a ground glass screen was set up in the image plane of the lens and a careful inspection of the image was undertaken.

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* The zero frequency response of a lens, strictly speaking, has no meaning as the lens has a finite and bounded field. For a 40 mm field, the lowest frequency that has any significance is 1/40 pattern per mm, which is equivalent to a video frequency of approximately 10 kc/s.

In the case of the 3-15 in. Watson lens, it was immediately apparent that all was not entirely as desired. The covering power over the central 40 mm of image was inadequate at some settings of focal length and aperture. The effect of stopping down was to reduce the field noticeably; in addition, there were some curious geometrical distortions at the periphery of the field. On account of these undesirable features, the image was photographed for 20 different settings of focal length and aperture. As an example, one set of photographs is reproduced as Fig. 4 and a summary of the features of the whole set of photographs for the 3-15 in. range is given in Table 5. Thus it will be seen both from Table 5 and Fig. 4 that at f/6·3 at the 3 in. focal length setting there is a marked loss of definition near the periphery of the field. The small holes in the "Celotex" tiling of the studio show up quite clearly in the centre of the field, but they are very blurred near the edge. The 6 in. f/6·3 photograph shows a slight but definitely noticeable barrel distortion.

Summarising these observations, it may be stated that the covering power of the lens on this range is inadequate at certain settings and the image quality is not always good.

On the 6-30 in. range of the Watson lens, the field was larger and gave an adequate coverage over the central 40 mm under all settings. Apart from low contrast at the longer focal lengths, there were no obvious aberrations, with the exception of a slight tendency towards barrel distortion.

The Taylor, Taylor and Hobson lens was also examined for coverage and general image-forming properties. Here the coverage was always adequate, no geometrical aberrations or distortions were apparent from careful visual examination apart from slight barrel distortion. The reduction of field upon stopping down which was a very noticeable feature of the Watson lens was almost negligible with the Taylor, Taylor and Hobson lens. At some focal lengths the effect was completely absent and was only a second-order effect at other focal lengths. In any case, even when stopped down to f/128, the field was in excess of the required 40 mm diagonal. Six photographs were taken but no reproductions are given in this report, as there are no interesting distortions or defects, apart from the one already mentioned.

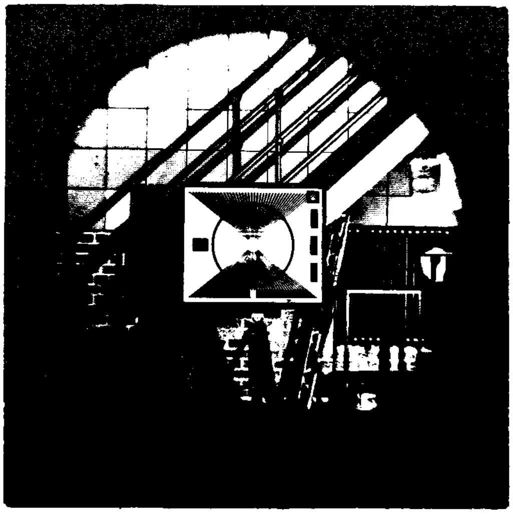
4. MECHANICAL AND OTHER CONSIDERATIONS.

4.1. Watson Lens.

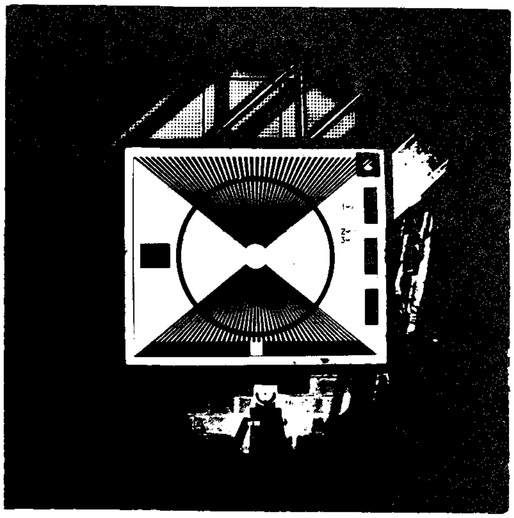
A slight lateral shift of the image was observed in the Watson zoom lens at the short focal length extremity. Its magnitude was less than 1 mm. A new Watson zoom lens which was sent to us straight from the manufacturers did not exhibit this slight peculiarity.

Some rusting of the interior metalwork was observed on Zoom No. 4 and trouble was originally encountered with condensation. It was found that the silica-gel desiccator was in the saturated condition (pink).

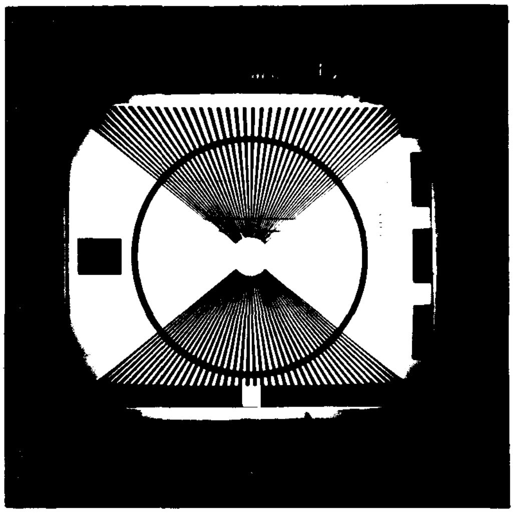
The control of the iris diaphragm is typical of the standard shape of iris blade and gives a contracted scale near the stopped-down end. An improved blade shape can be used to give a much more uniform control of aperture.



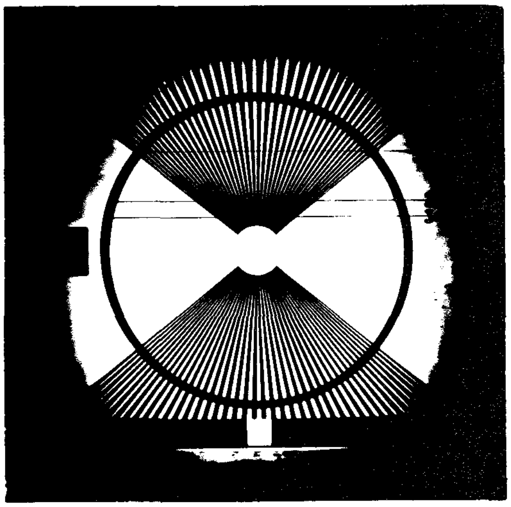
3" focal length



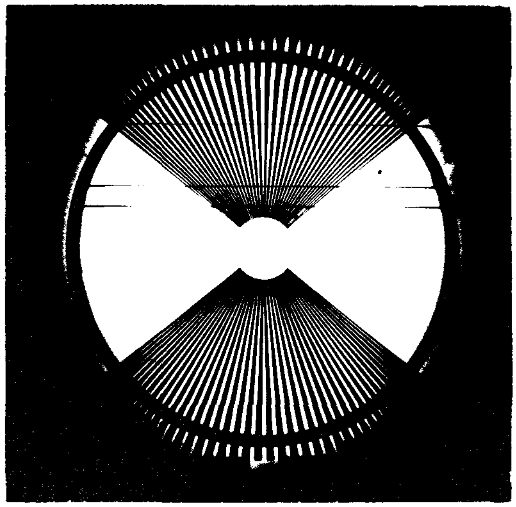
6" focal length



9" focal length



12" focal length



15" focal length

Fig. 4

Set of photographs illustrating general image quality of Watson Zoom lens at f/6·3 (3"–15" range)

(x 1·3 enlargement)

The Watson lens has a feature (not shared by the Taylor, Taylor and Hobson lens) of giving a larger aperture at the short-focus end. Thus, on the 3–15 in. end, it will open up to f/3 over the range 3–6 in. focal length, but thereafter gradually closes down to f/4·5 at 15 in. Likewise on the 6–30 in. range, from 6–12 in. focal length an aperture of f/6 is available, but thereafter there is a gradual closing down to f/9 at 30 in. It seems a rather doubtful point as to whether this extra light flux over a limited part of the complete range is a desirable feature. It may well, in fact, be a disadvantage since it gives a camera-man the impression that a scene is sufficiently well lit for the zoom lens to give satisfactory pictures. In consequence, upon zooming up to the longer focal lengths for a close-up, the picture deteriorates considerably owing to insufficient light flux on to the photo-cathode. Tables 6 and 7 give the modulation values for the Watson lens on both ranges at this variable maximum aperture.

4.2. Taylor, Taylor and Hobson Lens.

The servo power unit gave some trouble originally but after attention performed satisfactorily. The focus motor, which, it is understood, has had new "noiseless" bearings fitted, is now very sluggish in operation. At certain settings it seemed reluctant to start moving and occasionally required help. The zoom motor was of adequate power and operated well, but there was appreciable back-lash between the control and the operation of the servo motor. In the condition in which it was received, the zoom servo motor gave a zoom range of only 4:1.

A focal-length or angle-of-view indicator would be a desirable addition both for operational and also for test purposes.

It was noted that the aperture control is very uniform down to f/128. Whether it is desirable to stop any lens down to f/128 seems somewhat doubtful. The diffraction limit of a lens is such that at this low aperture, modulation to square waves at a pattern frequency corresponding to 3 Mc/s is about 42%. Theoretical calculations give f/64 as the lowest aperture at which the modulation to 3 Mc/s bars can exceed 80% and this would seem to be a more suitable lower limit for a lens used in television. The present experimental arrangements do not permit of the testing of a lens at f/128, but it would be interesting to know the results of operational experience (if any) when this lens is used at f/128. Photographs taken as f/128 show a perceptible "softening" of the definition although the overall result (as a photograph) is quite satisfactory.

5. CONCLUSIONS.

There is no doubt that from the point of view of optical performance, the Taylor, Taylor and Hobson lens is markedly superior. The mechanical arrangements on it are not above reproach, but some redesign of these should be well worth while on account of the good optical performance.

TABLE 1

AXIAL MODULATION/FREQUENCY CHARACTERISTICS FOR WATSON ZOOM LENS

The figures are percentage modulation to square waves

	Video Frequency Mc/s	Relative Focal Length					
		f	2f	3f	4f	5f	
Max. Aperture f/4·5	0	98	97	97	92	57	
	1	97	95	93_5	82_5	50_5	3 – 15 in.
	2	95	91	88	72	47	f = 3 in.
	3	89	85_5	84	64	42	
One stop down f/6·3	0	99	99	99	99	90	
	1	97	96	94	94	86	3 – 15 in.
	2	94_5	91	87_5	87_5	82	f = 3 in.
	3	91_5	87	82	81	76	
Max. Aperture f/9	0	98	98	97	82	54	
	1	93_5	92	84	62	39_5	6 – 30 in.
	2	87	83	78	47	30	f = 6 in.
	3	80	75	69	37	26	
One stop down f/12·5	0	99	98	93	96	95	
	1	96	93	88	88	82	6 – 30 in.
	2	89	87	82_5	76	66	f = 6 in.
	3	82	82	76_5	66	55	

TABLE 2

AXIAL MODULATION/FREQUENCY CHARACTERISTICS FOR TAYLOR, TAYLOR AND HOBSON ZOOM LENS

The figures are percentage modulation to square waves

	Video Frequency Mc/s	Approx. Relative Focal Length					
		f	2f	3f	4f	5f	
Max. Aperture f/5·6	0	99	99	97	96	97	
	1	96	95	91	90	92	5 – 25 in.
	2	90	86	84	83	84_5	f = 5 in.
	3	81	79	78	76_5	76	
One stop down f/8	0	98	98	97	97	96	
	1	97	95_5	95	94	92	5 – 25 in.
	2	94_5	91	91	91	87	f = 5 in.
	3	91	87	86	85_5	80_5	

TABLE 3

AXIAL MODULATION/FREQUENCY CHARACTERISTICS FOR WATSON ZOOM LENS

The figures are modulation to sine waves expressed in decibels

	Video Frequency Mc/s	Relative Focal Length f	2f	3f	4f	5f	
Max. Aperture f/4·5	0	-0·2	-0·3	-0·3	- 0·7	- 5·5	3- 15 in. f = 3 in.
	1	-0·4	-0·6	-0·9	- 2·1	- 6·6	
	2	-1·0	-1·5	-1·8	- 3·7	- 7·8	
	3	-1·7	-2·2	-2·8	- 5·4	- 9·6	
One stop down f/6·3	0	-0·1	-0·1	-0·1	- 0·1	- 0·9	3- 15 in. f = 3 in.
	1	-0·4	-0·6	-0·8	- 0·8	- 1·7	
	2	-0·9	-1·3	-1·6	- 1·7	- 2·6	
	3	-1·4	-2·0	-2·3	- 2·7	- 3·9	
Max. Aperture f/9	0	-0·2	-0·2	-0·2	- 1·7	- 5·2	6- 30 in. f = 6 in.
	1	-0·9	-1·1	-1·5	- 5·2	- 9·0	
	2	-1·8	-2·3	-3·1	- 8·4	-12·0	
	3	-2·9	-3·6	-4·8	-10·8	-14·0	
One stop down f/12·5	0	-0·1	-0·1	-0·6	- 0·4	- 0·4	6- 30 in. f = 6 in.
	1	-0·8	-0·7	-1·4	- 1·5	- 2·5	
	2	-1·8	-1·7	-2·4	- 2·7	- 5·1	
	3	-2·8	-2·8	-3·4	- 5·0	- 7·2	

TABLE 4

AXIAL MODULATION/FREQUENCY CHARACTERISTICS FOR TAYLOR, TAYLOR AND HOBSON ZOOM LENS

The figures are modulation to sine waves expressed in decibels

	Video Frequency Mc/s	Approx. Relative Focal Length f	2f	3f	4f	5f	
Max. Aperture f/5.6	0	-0·2	-0·1	-0·3	-0·3	-0·2	5 - 25 in. f = 5 in.
	1	-0·7	-0·8	-1·2	-1·2	-1·0	
	2	-1·7	-2·1	-2·1	-2·2	-2·2	
	3	-3·2	-3·4	-3·4	-3·2	-3·5	
One stop down f/8	0	-0·2	-0·2	-0·3	-0·3	-0·3	5 - 25 in. f = 5 in.
	1	-0·4	-0·6	-0·6	-0·7	-0·9	
	2	-0·9	-1·1	-1·2	-1·2	-1·7	
	3	-1·4	-1·6	-1·8	-2·0	-2·6	

TABLE 5

RESULTS OF PHOTOGRAPHIC TESTS ON THE WATSON ZOOM LENS

3 - 15 in. Range

Focal Length	COVERING POWER Over Central 40 mm			IMAGE QUALITY		
	f/4·5	f/6·3	f/22	f/4·5	f/6·3	f/22
3 in.	Central 38 mm satisfactory	Adequate	Adequate	Corner definition poor	Loss of definition in corners	Loss of definition in corners
6 in.	Central 38 mm satisfactory	Central 39 mm satisfactory	Central 39 mm satisfactory	Vignetting prevents assessment	Good	Good
9 in.	Just adequate	Adequate	Central 39 mm satisfactory	Poor modulation	Fairly good	Good
12 in.	Not quite adequate	Adequate	Central 39 mm satisfactory	Tangential definition low	Fairly good	Good
15 in.	Adequate	Adequate	Central 39 mm satisfactory	Low modulation	Fairly good	Good

In addition to the above, slight barrel distortion is visible on most photographs taken at 6, 9, 12 and 15 in. focal length

TABLE 6

AXIAL MODULATION/FREQUENCY CHARACTERISTICS OF THE WATSON ZOOM LENS AT ITS MAXIMUM (NON-CONSTANT) APERTURE

Modulation to square waves

Video Frequency Mc/s	Aperture					
	f/3	f/3	f/3·4	f/4	f/4·5	
	Focal Length					
	3 in.	6 in.	9 in.	12 in.	15 in.	
0	0·97	0·95	0·93	0·64	0·57	
1	0·95	0·91	0·82	0·56	0·50$_5$	3– 15 in. range
2	0·87	0·86	0·67	0·49	0·47	
3	0·77	0·80	0·62	0·44	0·42	

Video Frequency Mc/s	Aperture					
	f/6	f/6	f/6·8	f/8	f/9	
	Focal Length					
	6 in.	12 in.	18 in.	24 in.	30 in.	
0	0·96	0·98	0·91	0·55	0·54	
1	0·85	0·85	0·55	0·37$_5$	0·39$_5$	6 – 30 in. range
2	0·76	0·73	0·38$_5$	0·27	0·30	
3	0·68	0·64	0·31	0·22$_5$	0·26	

TABLE 7

AXIAL MODULATION/FREQUENCY CHARACTERISTICS OF THE WATSON ZOOM LENS AT ITS MAXIMUM (NON–CONSTANT) APERTURE

Modulation to sine waves

Video Frequency Mc/s	Aperture				
	f/3	f/3	f/3·4	f/4	f/4·5
	Focal Length				
	3 in.	6 in.	9 in.	12 in.	15 in.
	db	db	db	db	db
0	−0·2	−0·4	−0·7	−3·9	−5·5
1	−0·8	−1·1	−2·2	−5·5	−6·6
2	−2·1	−2·2	−4·4	−7·5	−7·8
3	−3·5	−3·5	−5·9	−9·0	−9·6

3–15 in.
range

Video Frequency Mc/s	Aperture				
	f/6	f/6	f/6·8	f/8	f/9
	Focal Length				
	6 in.	12 in.	18 in.	24 in.	30 in.
	db	db	db	db	db
0	−0·3	−0·2	− 0·7	− 5·2	− 5·4
1	−1·8	−1·7	− 6·7	− 9·9	− 9·0
2	−3·4	−2·8	−10·2	−13·2	−12·0
3	−5·5	−5·0	−12·2	−15·1	−14·0

**6– 30 in.
range**